



Watching Quasiparticles Move

Exploring the Nonequilibrium Dynamics of Superconductors

An LBNL team led by Joe Orenstein has developed a new optical technique for determining precisely the diffusion coefficient and scattering rates of “quasiparticles” in high- T_c superconductors. Their initial results, from single crystals of $\text{YBa}_2\text{Cu}_3\text{O}_{6.5}$, reveal that high-energy quasiparticles in such materials propagate remarkably far, several hundreds of nanometers, before decaying into lower energy quasiparticles or pairing with each other to form “Cooper pairs.”

Superconductivity occurs when electrons come together to form Cooper pairs. The pairs condense into a resistanceless charged fluid, which leads to a state of zero electrical resistance. This zero resistance persists even if some of the pairs separate (the unpaired electrons that form in this process are called quasiparticles in the language of condensed matter physics). Viewed from this perspective, quasiparticles have a shadowy existence, as their contribution to resistance is completely “short-circuited” by the Cooper pair condensate. Nevertheless, in the wider world of superconductivity and its applications, quasiparticles play a crucial role. In x-ray detectors, quasiparticles carry the charge that is detected when a photon impinges on a superconductor. In superconducting Josephson junctions, which are under investigation as the building block of a quantum computer, quasiparticles lead to undesired “decoherence.” Thus, the dynamics of quasiparticles, specifically their rates of diffusion, scattering, trapping, and recombination, are critical for the both the applications and fundamental understanding of superconductivity.

Because quasiparticles do not contribute to the resistance of a superconductor, prior investigations of their dynamics have been indirect. In the new LBNL technique, two ultrashort laser pulses incident on the sample at a carefully controlled angle create a standing wave of intensity, generating a periodic variation in the density of quasiparticles just below the superconductor’s surface. Because the index of refraction depends on the local quasiparticle density, the surface of the superconductor becomes a diffraction grating. The amplitude of the grating, and hence the crest to trough variation in quasiparticle density, can be measured by a probe beam arriving at the sample after a variable delay time on the order of picoseconds (see figure). Following its creation, the grating decays due to the combined effects of recombination (in which quasiparticles reform superconducting Cooper pairs) and diffusion. By adjusting the angle between the two pulses that create the quasiparticles, gratings with spatial periods between 2 and 5 microns were made. Analysis of the decay rate of the grating as a function of the spatial period allowed the effects of recombination and diffusion to be separated. The team found diffusion coefficients of 20, or 24 cm^2/s (depending on orientation with respect to the crystal axes) and a recombination lifetime that reached 100 picoseconds at low quasiparticle density. Together these parameters imply a quasiparticle diffusion length of approximately 400 nm, which is remarkably large for high-energy quasiparticles.

The results represent the first direct study of the dynamics of quasiparticles in a high T_c superconductor. The surprising discovery that they can propagate over relatively large distances provides a challenge to theorists to explain, as well as opportunities for applications that involve detection of nonequilibrium quasiparticles.

J. Orenstein (510) 486-5880, Materials Sciences Division (510 486-4755), Berkeley Lab.

N. Gedik, J. Orenstein, Ruixing Liang, D.A. Bonn, and W.N. Hardy, “Diffusion of nonequilibrium quasiparticles in a cuprate superconductor,” *Science* **300**, 1410 (2003).